A review of critical problems from the desks of chief executive officers in the passenger railway service industry

M. D. Mc Naught & C. J. Fourie
Department of Industrial Engineering,
Stellenbosch University, South Africa

Abstract

In the passenger railway service industry, there are a plethora of problems and everyday, big decisions have to be made by executives as to which problems are most important. The key areas of a passenger railway service company are identified by conducting a customer needs analysis. These needs are then converted into operational requirements, which are considered to be the functional 'building blocks' of the company. An asset management cost analysis method is employed to determine three critical cost areas from the financial statements of ten passenger railway service companies. This gives executives a financial handle to engineering problems. The problems are discussed from an engineering perspective and a solution method is presented which will save cost in safety, maintenance and operations domains.
Keywords: railway, reliability, needs analysis, infrastructure, maintenance, safety.

1 Introduction

Passenger railway service companies, like other large companies, have multiple complex problems affecting the profitability of the company. These problems are the costs which hold the company back from excellent financial performance. These problems especially affect passenger railway service companies in developing countries who have not developed systems to effectively manage more than a few key problems, at any given time [1]. Thus, it is necessary to develop a methodology which simplifies the multitude of problems experienced into a more manageable set of key performance affecting problems.

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The developed methodology will allow effective communication between engineering managers and financial officers, which is where the handle is often lost on problems, due to prioritisation discrepancies between engineers and financial representatives [2]. The prioritisation of problems is also often lost in the complexity of trying to manage and run the business. Redirecting to the correct focus, the key identified problems are centred on customer needs. When these needs are satisfied, the business becomes more profitable. Thus, a tool is developed which identifies key problems which are not only costly to the business, but also important for the sake of customer satisfaction.

From a process of inductive reasoning and questioning, the following research objectives are set:

- Present finance-based evidence which justifies the severity ranking of different engineering problems.
- Determine a ranking of importance for compared customer needs.
- Conduct an analysis of problem topics from three critical problem domains.
- Present potential solutions for the sake of continued research.

2 Cost analysis method

A cost analysis method was designed to determine a critical improvement area in a developing passenger railway company (such as rolling stock quality control or infrastructure maintenance). The idea behind the method is to determine the basic functional 'building blocks' of the railway company, based on the needs of the customer. The building blocks or 'costs' are then compared on an operating cost basis, using the financial statements from ten railway companies.

2.1 Customer needs analysis

As the passenger railway service industry is service focused, the researcher argues that the 'building blocks' that make up the railway system should exist to fulfil customer needs.

Two interviews were designed; following the customer needs process developed by Takai and Ishii [3], to evaluate the customer needs of passengers in Railway Company A in South Africa. The procedure of the discussed customer needs development process is outlined. Sampled customers were first interviewed using a questionnaire to identify customer needs of the railway service. The customers were then asked to use the Subjective Clustering method (SC method) to group similar customer needs, which is discussed by Takai and Ishii [3]. The sample of customers was then asked to use the Affinity Diagram method, (AD method) which is the validation method for the grouping of customer needs [3]. The second interview was conducted, in which customers were given the refined needs and were asked to rank them based on importance. Customer needs were then ranked by the researcher, based on the customer collected information.

The interviews were conducted on an individual basis and account for customers who travel for both work and recreational purposes. The selected train station (Stellenbosch, South Africa) accurately captures a varying demographic as there are train users there who are students from the University, business men and woman from higher income and lower income classes and locals from the nearby township. An even number of customers from each demographic were interviewed. The interview results are presented in Fig. 1.

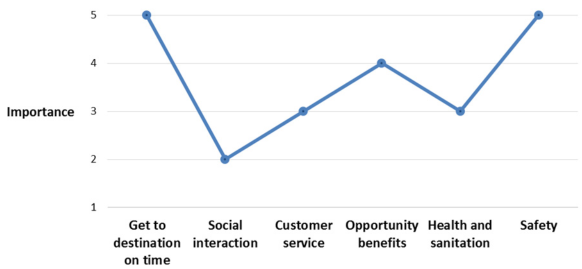

Figure 1: Importance diagram of refined customer needs.

Fig.1 shows six clearly defined customer needs, which were cross correlated between the SC method and the dendrogram from the AD method [3]. The interviews revealed that safety and arriving on-time are the needs most important to the customer base.

2.2 Most basic system operational requirements 'building blocks'

The needs from the customer base are converted into system operational requirements to determine key 'building-blocks' in the railway company. The format of the operational requirements is extracted from Blanchard and Fabrycky [4]. The operational requirements for a passenger railway service company comprised of: a mission definition, performance parameters, operational deployment, operational life cycle, utilisation requirements and environmental factors. The operational requirements reveal 'building blocks' which make-up the railway network from the business end. Fig. 2 illustrates a summary of the 'building blocks'.

2.3 Cost comparison from the financial statements

The 'building blocks' of the railway network are converted into 'costs' common to the financial statements (2012–13) of ten passenger railway companies, which are public documents. Any finance used to sustain a building block is considered to be a 'cost'. Each cost is compared on a yearly basis to ensure equivalency. For instance, capital debt is measured by interest expenses and loan repayments and land and buildings are measured by renewals, renovations and maintenance. Consistently high costs across different railway company's financial statements are considered to be critical costs, which is the focus point of this investigation.

Figure 2: 'Building blocks' of a passenger railway network.

This method is similar to the life cycle costing method by Marquez *et al.* [5]. They compare costs on a lifetime basis, whereas this researcher compares costs on a yearly operational basis. Table 1 presents costs for ten passenger railway companies, including the totals for each cost and the totals for each company.

Table 1: Company 'costs' from 'building blocks' for ten passenger railway service companies.

Cost ($ millions)	Company										Total
	Amtrak	ARTC	China Railway Group ltd	Deutsche Bahn	Ferrovie Italiana	Indian Railway	JR Central	Network Rail	PRASA	SNCF	
Capital Debt	567.00	28.16	14938.36	21092.04	20969.18	746.33	3914.58	48117.68	487.01	9447.38	**120307.74**
Customer service	101.67	-	121.01	888.50	1.74	0.03	110.98	140.99	24.35	846.23	**2235.49**
Infrastructure	772.67	185.18	20740.99	12264.11	1699.76	0.03	2059.98	2672.32	138.46	5110.80	**45644.30**
Land & Buildings	246.64	159.20	1798.77	5411.65	295.02	0.01	626.98	6340.03	45.27	2784.32	**17707.90**
Maintenance	205.20	-	-	27058.26	1475.11	-	-	951.00	78.84	-	**29768.41**
Operations	905.495	3.72	-	21493.3	-	-	7459.97	6308.33	264.58	1575.42	**38010.82**
Rolling Stock	877.57	-	-	6671.35	596.32	0.03	1653.48	-	232.31	-	**10031.06**
Safety	321.37	22.27	-	370.40	304.80	-	304.80	-	85.72	986.41	**2395.74**
Telecommunications	378.43	12.33	242.02	2739.01	3.49	0.18	1972.89	-	74.30	1126.59	**6549.22**
	4376.04	**410.84**	**37841.15**	**97988.61**	**25345.41**	**746.61**	**18103.66**	**64530.36**	**1430.85**	**21877.14**	

The companies include the largest passenger railway companies as well as companies with the most ridership. Some of these large companies deal only in infrastructure, hence the exclusion of some financial information. Other financial exclusions are due to the generality of some financial statements.

Fig. 3 presents the costs for the ten passenger railway companies and validates the results through a basic trend analysis. There is an observed correlation between highest cost and importance of the cost to a company. The observed trend in Fig. 3 identifies the top three (critical) costs for passenger railway companies. Companies seek to reduce expenditure to optimum thus capital debt, infrastructure and operations have earned priority for the purposes of investigation. It is argued that because maintenance has a contribution to the expenditure of infrastructure, it should also be investigated as a critical cost.

An engineering investigation is to be conducted on critical company costs, thus capital debt can be ignored. Another concern is that companies spend too little on safety, considering that safety is one of the drivers on the mission statement of many of the investigated companies. Thus a common thread is sought in literature between infrastructure, operations, maintenance and safety. The proposed research idea is to improve infrastructure expenditure through better maintenance and operations tactics, thus improving safety as well.

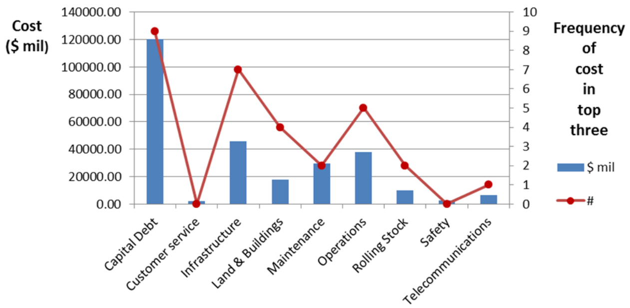

Figure 3: The total of each 'cost' across ten railway companies and the number of times each cost was a critical cost to an individual company.

3 Literature study

Maintenance, operations and safety topics are investigated to see how they relate to the infrastructure division of a passenger railway service company.

3.1 Maintenance

The current established method for railway track maintenance in South Africa is condition-based maintenance, using a track geometry rail car [6]. Track cars are driven along the South African circuit to determine poor sections of track by measurement and statistical analysis. Standard deviation of track geometries from the design conditions are used to construct a Track Quality Index (TQI). Poor track sections are thus identified and maintenance schedules are created around this information.

New approaches in preventative maintenance on rail tracks are being investigated by Minsili *et al.* [7]. They have developed a ballast renewal strategy which allows for improved long-term health of the track network, thus saving replacement and maintenance cost. The effectiveness of this method could pave the way to a movement in the direction of preventative maintenance for tracks. Oyama and Miwa [8] developed an All-Integer Linear Programming (AILP) optimisation model for optimum railway track scheduling. The model minimises maintenance cost and maximises aggregate ride quality and safety levels of railway track. The schedule of a multiple tie tamper (MTT) is used for optimisation. This machine repacks track ballast and corrects deviant track geometry. Tamping is a condition type maintenance method, but advance planning and route optimisation provides structure for the addition of preventative maintenance methods. Higgins [9] considered a train operations schedule and minimised the number of times that scheduled maintenance should clash with train operation. A tabu local search optimisation method was used to process the large amount of decision variables in the problem. This shows that track maintenance not only needs to have optimal routes for maintenance but also specific times for maintenance, in accordance with a train operating schedule. An 8% reduction in interference delay was achieved on a train schedule.

Current track maintenance methods involve condition-based and reactive maintenance. Schedules are planned in advance but reliability and optimisation strategies are lacking. New research in preventative maintenance, coupled with condition-based approaches seems to be a rich avenue for exploration.

3.2 Operations

The infrastructure of a rail company affects operations when infrastructure faults cause delays and speed restrictions. Maintenance of infrastructure can also have schedule clashes with train operations, all of which have an opportunity cost. Capacity issues lead to capital expenditure for upgrading infrastructure. Performance indicators developed to trace railway operations can be used to monitor infrastructure performance.

The press in South Africa (official) reported that the Railway Safety Regulator issued an improvement initiative to Metrorail Western Cape, in March 2014 [10]. Speed restrictions of 15km/h were imposed on lines outside Cape Town station as the infrastructure was declared to be in unsafe condition. In 2014, Network Rail under-spent £1.2bn on maintenance [11]. Infrastructure faults caused a 1–5% increase in missed punctuality targets. This increase in delays caused a £53 million fine by the Office of Rail Regulation. Sudden failures cause a blockage in service as trains are delayed while faults are being fixed. This is the case for Network Rail. Poor maintenance of infrastructure ultimately leads to unreliability, discounting the top customer need according to the customer needs analysis. These negative effects on operations could be better controlled with more structured track maintenance.

Railway infrastructure is linked directly to the capacity of a rail network, which is governed by size of the locomotive fleet, the extent of infrastructural development and train scheduling. During peak hours, the most trains will be in service and infrastructure failures could have an effect on train delays across the fleet. Shcherbanin [12] investigated Russia's railway problems, highlighting capacity bottlenecks as one of the most significant problems. A capacity bottleneck could be seen as a single-carriageway train line, which is not only an operational complexity, but also a critical problem area when considering infrastructure failures. This leads to a conclusion that high traffic single-carriageway tracks have to be maintained to a higher standard, with a higher reliability than other track sections. Gevert [13] also encountered capacity issues during company expansion, during Brazil's Carajas railway project. Solution methods included doubling up carriageways, at a huge capital expense and also increasing train length. Each solution method requires higher maintenance expenditure on the tracks, thus capacity issues are a large driver of infrastructure expenditure increases. Infrastructure research should enable higher track reliability at a lower cost, thus alleviating capacity issues by a quantifiable amount. Trains will then be able to travel faster and more safely, with a lower risk of failure on bottleneck track sections.

Key Performance Indicators (KPIs) are often used in the operations division to monitor specific areas of performance and to compare and improve efficiency of processes. This tool can be applied to infrastructure to give helpful performance targets for maintenance activities. Ahren [14] provided a definition of a key performance indicator. A ‘performance indicator is a measure capable of generating a quantified value to indicate the level of performance taking into account single or multiple aspects’. When researching improvement strategies for infrastructure, these performance indicators can be used as a guide-line to ensure that valuable improvements are being made. Banverket (Swedish rail) used Maintenance Performance Indicators (MPIs) that affect infrastructure, namely: train delays due to infrastructure, number of train disruptions due to infrastructure, capacity restrictions, markdowns in current standard (speed restrictions), total number of urgent inspection remarks and Track Quality Index [15]. These indicators are a guideline for research on improvement areas for infrastructure. Stenström *et al.* [16] used a link and effect model to convert railway business objectives in to KPIs that are then analysed and implemented. This method allows for useful captured data to be converted into output. This model was applied to the Iron Ore line in Sweden and it proved to be efficient, when used in conjunction with other computer analysis software. KPIs can be developed for infrastructure research for a case-study company. Research can then be applied to the company and the suggested improvements will be measured using KPIs. From these KPIs, an implementation strategy will commence to realise the discovered improvements.

3.3 Safety

Infrastructure failures have a safety impact on train passengers, with the most detrimental being derailment. Infrastructure related incidents also cause death and injury of company workers. Safety has been identified as the top priority for customers in the needs analysis presented and most railway companies analysed, declare safety as one of their key performance areas.

An analysis of fatal train incidents in Europe between 1980 and 2009 was conducted by Evans [17]. For the nine countries analysed, infrastructure was the second highest cause of fatal train collisions for seven countries and it was the fourth highest cause for two of the countries. There were a total of 277 fatal train collisions during this period. Kyriakidis *et al.* [18] identified infrastructure technical failures as a key precursor to railway accidents. They developed a methodology which seeks to reduce precursors such that accidents can be prevented. The methodology was applied to eighteen of the world’s major metros. Investments in infrastructure to reduce risk of accident was agreed to be one of the solutions to mitigate precursors. Reliability improvement of railway was also listed as a pro-active solution in the infrastructure domain. American rail fatalities and incidents were investigated by Liu *et al.* [19], with specific focus on infrastructure failures. The top cause of derailment was broken rail and welds, followed by track geometry defects. These failure modes not only cause a safety hazard, but also disrupt operation of the trains, causing further losses. Infrastructure failures caused more derailments than rolling stock, indicating that infrastructure is a high safety priority for railway companies. It was also proven that derailment risk decreases as the condition of the track improves. This indicates that there is a relationship between probability of failure and track condition, which opens up an interesting avenue of research for infrastructure reliability.

Thus, in order for passenger railway companies to keep a solid reputation, as well as maintain reliability standards and safe-guard human life, infrastructure improvement and maintenance should be taken seriously.

4 Solution methods through research

The researcher analysed literature on solution methods to the identified critical 'cost' problems. The idea is to identify solution methods even if they haven't been used for railway before. A research avenue is thus created in which problems can be tackled in more detail. Two potential solutions are discussed for further research consideration, such that practical implementation will arise.

The definition of reliability is provided as a guideline for discussed methods: 'Reliability is the probability that a component will operate correctly for a specified portion of time (design-life) under the design operating conditions (amp, temperature, force) without failure [20].'

4.1 TQI derailment solution

The Track Quality Index (TQI) is a current tool used in the railway industry to monitor the condition of the tracks and thus schedule maintenance based on track condition. This is a useful maintenance tool, but it lacks the power of scientific methods such as reliability. Thus, a relationship is sought between TQI and reliability to capture the ease of using TQI, with the powerful output of reliability methods. With TQI, a standard deviation statistic is assigned to a track section based on the deviation from design geometric track parameters.

A reliability block diagram can be developed for a track system based on reliability methods for each track component. The basis of this reliability model is the probability of train derailment caused by geometric rail irregularities. Derailment is considered to be failure of the track system according to the definition, thus a reliability basis for the system is established. This method produces a single reliability statistic for each track section, based on estimation, from which a track maintenance schedule can be built. Critical reliability statistics require more immediate maintenance attention.

For this solution method to succeed, reliability methods for each track component need to be identified from literature. These methods each need to be applied to a case study which has failure information for each track component for an entire rail network. Each rail section also needs to have up-to-date geometric measurements, which are available. As TQI is based on standard deviation of rail and the rail reliability also depends on standard deviation, some relationship can be constructed between TQI and rail reliability. TQI derailment is a heavily computational method and it requires extensive data extraction. It also requires efficient capturing of data by the company, which may not be the case in third world countries. Data this extensive may also not be available by most railway service companies.

4.2 Track failure reliability map

As a starting point, a fault tree analysis and a Failure Modes and Effects Criticality Analysis (FMECA) must be directed in order to understand the cause and effect of railway track failures. The failure modes must be well understood as only failure modes that affect the operation of trains will affect track reliability. This is according to the definition, as any component acting apart from design conditions (failure) is considered to be unreliable.

Once the failure modes are understood, a dataset of track incidents must be obtained. This dataset is then filtered to only include failure modes that affect the operation of trains. A speed restriction or potential train stoppage is considered to be an effect worthy of unreliability. Reliability methods can be applied to the remaining data to determine a reliability map for the train network. Each track section should have a reliability statistic, which will allow for an optimisation of maintenance routes, required to restore track sections to a more reliable state. The reliability statistics will also give train drivers an idea of how to navigate the track sections ahead, when embarking on a trip. This reliability map will not only reduce wear and tear of rolling stock components through better route navigation, but it will also save maintenance cost of infrastructure through maintenance route optimisation.

4.3 Discussion of solution methods

The two discussed solution methods each compute reliability from a different reference point. The TQI derailment solution uses derailment as a baseline reliability failure. Track failure reliability map views the change in operating conditions in the rail network due to infrastructure failures as unreliabilities in the system. The two different approaches discussed are relevant because each have different degrees of applicability to a practical context. The changes in operating condition approach uses actual operations and failure data to arrive at network reliability, rather than using more abstract TQI information. Probability of derailment is the most theoretical as some train networks have very few derailments in actuality. This method goes by the assumption that railway conditions are driven by safety, away from the fears of derailment. Therefore, in applying theory to practice, the ‘Track failure reliability map’ is the most relevant method.

The difficulty of data capture also needs to be low to ensure that the chosen method can be applied to different railway companies with relative ease. The

Track failure reliability map solution has the data capture method with the easiest access to information that most companies are likely to have available. TQI derailment, on the other hand is complex as a vast array of individual component failures need to be available to produce reliability information. In practice, such detailed information may not be available. The track failure reliability map is thus the preferred method for data capture purposes.

The final judgement of the solution methods is the computational difficulty of the proposed solution. TQI derailment has the most complex computational process as it contains a number of reliability method computations for each railway component in a track section. Track failure reliability map has the least complex computational process as reliability statistics simply need to be computed from spread out actual component failures, which are grouped into separate track sections. Each method could use maintenance schedule optimisation thus computation time for this procedure is effectively even.

5 Conclusion

The 'Track failure reliability map' solution clearly has the most benefits as a research initiative. It is difficult to say which method would reduce company costs the most, but it certainly wouldn't be the best method is it wasn't possible to implement. Track failure reliability map is therefore the best solution to eliminate critical problems from the desk of CEOs in the passenger railway industry. It is further noted that the research objectives were met through this solution method.

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